Chapter III

General Environment of Coast of Gulf of Cambay
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3.1 Location of Study Area

The Gulf of Cambay (Khabhat) situated between longitude 71° 30’ and 73° 10’ E and latitude 20° 30’ and 22° 20’ N is an inverted funnel shaped (70 km wide, 130 km long) indentation on the western shelf of India (Figure 3.1) between the Saurashtra peninsula and the mainland of Gujarat (NIO, 1992). On the western side, the Gulf starts from Gopnath Point and lies between the coasts of Surat and Valsad districts on the eastern side. Due to its peculiar oceanographic features such as high tidal amplitude, the region is comparatively less explored than the other gulf regions. However considerable explorations have been conducted on the nearshore estuarine environment and coastal geomorphology (Desai, 1999).

The gulf is tectonically controlled and is delineated by the various Cambay Basin bounding faults. Geologically and geomorphologically its different parts are quite distinct, and the gulf presents a complex picture of sediment input, sediment transport and deposition. The gulf comprises an area of high tides (upto 11 metres) and is characterized by domination of strong tidal currents. The tidal current directions during flood and ebb tides follow almost identical paths and reflect the bathymetric features of the gulf. The coastal features are also related to the behaviour of tides and tidal currents. The tidal currents have mainly been responsible for most of the depositional and erosional features of the gulf. The topography of the gulf bottom comprises numerous underwater ridges, deep channels and shoals. These features are the reflection of the initial presence of graben faults that were subsequently modified by sediment accumulation by tidal currents. The linear sandy ridges which themselves are the creation of tidal currents, now control the tidal current direction and the pattern of sediment
Figure 3.1 Gulf of Cambay
transport and deposition. This gulf forms a funnel-shaped entrant of the Arabian Sea (Figure 3.2) rather abruptly and is located in the widest portion of the West Coast continental shelf. The sea inlet forming a Quaternary coast is characterized by the highest tide rise along the west coast, is endowed with various geological and geomorphological diversities and provides a baffling picture of coastal marine processes involving transport, deposition and redistribution of sediments. The waters of the gulf are highly loaded with fluvial sediments brought from the mainland side and are constantly churned up by tidal currents. The extreme muddiness of the gulf water flow has resulted into an interesting assemblage of depositional landforms in and around the gulf. The outer trough (around 21° 40' N) is sufficiently deep and navigable in the mid east, but the western region is relatively shallower. The outer trough soon bifurcates into two channels, which encircle the candy shallows of Malbank between 21° 45' N and 22° 02' N (Figure 3.3). The eastern channel is unnamed and shallower with a longitudinal sediment ridge called Makra bank. The Western channel is called Malcom channel and is deeper (Figure 3.4). The Malcom channel has been used for navigation since ancient times. Both eastern and Malcom channels open to Khambhat (Cambay) channel, north of Mahi bank, heading to the estuarine mouth of Mahi river. Due to siltation from Mahi and Sabarmati rivers, Khambhat channel is shallower.

3.2 Transient nature of Coast of Gulf of Cambay

The coast of Gulf of Cambay being a very dynamic environment, enthralls scientific interest while posing a channel to cope up with the environment. Very high tidal amplitude, extreme amounts of temporal-spatial sedimentation, shifting of bathymetric relief features, constant shoreline changes and oscillatory movement of mudbanks and tidal flats pose enormous difficulty for development work as well as for coexistence with nature. In broad terms hazard is an inbuilt natural component of coast of Gulf of Cambay and is manifested in multitude of
Figure 3.2 The Gulf of Cambay forming a funnel shaped entrant of Arabian Sea
Figure 3.3 Gulf of Cambay area between Dholera and Bhavnagar
Figure 3.4 Contour map of Malcom Channel area
ways. Generally there are two very distinct components of changes in the form of hazards in the region namely:

1. Those that are generated by environmental progression (Natural changefulness)
2. Those that are generated at the interface between the man and nature (Human induced change)

1. Changes generated by environmental progression

Broadly, three types of interrelated changes are predominant which are as follows:

(i) Sedimentation and channel changes
(ii) Shoreline changes
(iii) Mangrove changes

(i) Sedimentation and Channel changes

The sediment derived from large catchment area consisting of tidal flats, estuaries and creeks remained suspended in the gulf water for long time period. The monsoon weather and the tidal influx scour the sediment from channel beds as well as from the shoreline and turn the upper gulf water especially turbid. It is also known from the literature that the setting of these sediments occur during the winter month. Therefore, in the cycle of sediment dynamics in the region, three fourth of the year encounters sediment removal and resuspension while the other fourth exhibits settlement. Both the processes of sediment removal and deposition are extremely hazardous to human interest in the region thus making the system extremely challenging throughout the year. Besides the accretion and erosion, both on the shoreline and the seabed are so dynamic that a complete migration of navigable channel called Malcom Channel by 2 km in the last 150 years has been recorded (GEONICS, 1996). This migration has also been due to the fact of lateral growth of a large sedimentary bank now known as Mal Bank in the middle
of the upper gulf. Apart from this dramatic change in this bathymetric feature, many small and subtle changes on the sea floor have been recently recorded (DPL, 1999).

(ii) **Shoreline changes**

The shoreline around the Gulf of Cambay is highly indented as well as moderately wavy. The shoreline of the mainland indented due to the presence of major estuaries and narrow creeks. The shoreline of the Saurashtra coast is less indented and appear moderately straight. The shoreline is marked by the presence of wide mudflat, estuaries, islands, submerged shoals, dunes and the absence of sandy beaches. The changes in the shoreline, especially in the Mahi and Narmada estuary, are significant. The erosional processes are predominant in the Mahi estuary while depositional activities are dominating in the Narmada estuary. The analysis of multidate Landsat imagery indicated significant shoreline changes in the Mahi and Narmada estuaries between the year 1972 and 1980. These changes in the Mahi estuary were reported by Nayak & Sahai (1984). As per their studies, complex erosional and depositional changes were noticed in the estuary, which were as follows:

- Between March 1973 and March 1975, the Mahi river has changed its course west of Dabka and shifted southwards to curve out two Islands. Increased deposition is noticed from 1977 imagery.
- Severe erosion was noticed near Dhuvaran during 1977-1981.
- Islands/shoals in the mouth near ‘Dabka’ have grown considerably after the year 1981 and now they have joined the mainland in the north. Further the aforesaid studies indicate complex depositional changes in the Narmada estuary. The size of the Aliabet Island has increased considerably between 1891 and 1977. The island has further grown eastward and joined mainland. Because of this, the southern channel has dried up. The increase in the size of the Aliabet Island suggests heavy deposition in the estuary. Using the recent
satellite data synergistically with topographic maps, shoreline changes in specific areas have been described by Mitra et al. (2000). This recent result indicates that there has been land erosion of 72.078 sq. km and an accretion of 5.196 sq. km when 1996 & 1999 imagery and 1967 SOI topographic maps were taken for respective analysis. The accretion may be due to the combined effect of land reclamation and sedimentary processes throughout the year (Mitra et al., 2000)

(iii) Mangroves Changes

The mangroves are highly adaptive flowering plant communities growing in the clayey, silty, intertidal coastal zones, deltaic and estuarine coasts and backwaters/ sheltered regions, in the tropical/ subtropical belts of the world. Mangroves are important as they help in the production of detritus, organic matter and recycling of nutrients and thus enrich the coastal waters and support benthic population of sea. Above all they provide feeding, spawning and nursery grounds to many organisms apart, from a vast range of direct and indirect products, benefits and services to the human being. In the Gulf of Cambay the area of mangroves has increased from 1996 to 2001 as is evident from the FCC images of the region and also from the supervised classification of the study area as shown in Fig 5.1 to 5.6. It can be further confirmed by the area of mangroves reported by FSI (1999) as shown in table 5.5. Though before 1996 the mangroves were showing a considerable decline in the study area.

3. Changes that are generated at the interface between man and the nature.

Basically two types of changes are dominantly visible in the recent records of satellite data of the region.

(i) Salt farming activity

(ii) Large scale industrial activity.
(i) **Salt farming activity**

The region is naturally endowed with hypersaline water of the gulf in addition to lack of rainfall and solar heat stress, which are good parameters for efficient and economically viable salt farming. Large tracts of tidal low lying land are seen to be encrusted with salt. Moreover the saltwater intrusion into the coastal aquifer has also made it feasible to pump the underground water into the salt farm instead of utilizing the tidal water. As an added fact salt farming is a low investment and high yielding activity and has been seen to have spread well in the recent past. The studies of recent satellite images have given a clear understanding on increasing of salt farming activity in the region. While in the initial date the salt farming were situated adjacent to tidal creeks, now there has been a trend of salt farming from the ground water in the areas not supported by tidal water.

(ii) **Large scale Industrial activity**

The west coastal region of Gulf of Cambay, being aesthetically poor and not so rich in biological reserve has attracted industrial establishment with less social opposition. A large portion of tidal flat area has already been transformed into a complex industrial salt farm for extraction of fertilizer quality chemicals by NIRMA Industries. This activity has rendered gross morphological change to the coastal landform in the area along with completely arresting the natural course of shoreline change.

Another large parcel of tidal land between two major creeks i.e. Sonari and Bavliali has been dedicated for the development of an all weather port by JK Industries. This tract of land, which is barren and salt encrusted at this moment, will witness the growth of large industrial park to feed the port activities. These two activities almost entirely transform the N- Western coastline of Gulf of Cambay and their influence on the nature would be enormous.
3.3 Description of weather and climate

General tropical climate of the region

The climate in the region is governed by its location in the tropics and by the monsoons. The climate is characterized by the annually recurring seasonal monsoons that divide the year into four seasonal monsoons that divide the year into four seasons which are as follows:

- The northeast monsoon period from December to March with predominantly northeasterly winds.
- The pre-monsoon period from April to May which is the hotter part of the year, May being the hottest.
- The southwest monsoon period from June to September mainly southwesterly winds.
- The post monsoon period is from October to November.

Rainfall

The annual rainfall in the area is approximately 500mm, half of which occurs in the month of July.

Temperature

January is the coldest month and the temperature can be as low as 4°C while May is the hottest month with temperature of up to 42°C.

Relative Humidity

In August, the average humidity is nearly 90% at 0800 hours while in January, it is about 45% at 1700 hours.
Visibility

Visibility is generally good in the area but deteriorate during rains and squalls in the monsoon months. According to the pilot studies of west coast of India, frequency of poor visibility of under 8 km was recorded around 2% in January and 35% in July.

3.4 Ecological and environmental characterization of the region

Shoreline

The shoreline around Gulf of Cambay is highly indented as well as moderately wavy. The shoreline of the mainland is highly indented due to the presence of major estuaries and narrow creeks. The shoreline of the Saurashtra coast is less indented and appears moderately straight. The shoreline is marked by the presence of wide mudflats, estuaries, islands, submerged shoals, dunes and the absence of sandy beaches. The change in the shoreline, especially in the Mahi and the Narmada estuary are significant (Nayak & Sahai, 1983, 1984, 1985; Shaikh et al., 1987a&b). The erosional processes are predominant in the Mahi estuary while depositional activities are dominating in the Narmada estuary.

Estuary

The Gulf of Cambay is characterized by a number of large and small estuaries appearing as if enclosed within a large one (the Gulf itself). Estuaries are largest and most complex of all landforms. All major estuaries like the Tapi, the Narmada, the Mahi, the Sabarmati, the Kim and the Dhadhar are marked by funnel shaped outline and tidal meanders, except the Narmada estuary, as evident from satellite imagery, which characterizes high tidal range. The estuaries are classified into salt- wedge estuary, fully mixed estuary (Pethick, 1984).

The Narmada estuary is classified as salt- wedge estuary where fresh water flow predominates. However due to the high tidal range, significant mixing also takes place because of strong tidal currents during high tide period. The
maximum deposition occurs in the mouth and this is evidenced by the presence of the Aliabet Island and its gradual expansion as reported earlier (Nayak et al., 1986, 1987; Shaikh et al., 1987a & b). This has blocked the channel south of the island resulting in filling up of the channel.

The Mahi, the Tapi and the Sabarmati estuaries are fully mixed estuaries as they experience strong tidal currents and weak discharges of fresh water. The sediments on left and right banks are different nature probably because of horizontal variation in salinity. The Dhadhar and the Kalubhar estuaries are partially mixed estuaries.

All these estuaries are drowned river valleys as per classification of Pritchard (1952). The rising sea level after last glaciation was responsible for the formation of these estuaries. They can be termed as coastal plain estuaries (Pritchard, 1952).

The Tapi, the Narmada, the Mahi and the Sabarmati estuaries bifurcate around islands and their appreciable infilling and are called estuarine delta (Nayak & Sahai, 1984, 1985).

All the estuaries are funnel shaped and are macro-tidal estuaries. In the funnel-shaped or trumpet-shaped estuaries, width decrease drastically upstream. Such a decrease in width produces a concentration of the energy of the tidal wave (Langbein, 1963). This concentration of energy might dissipate on the banks and riverbed. Thus deposition occurs mainly at the mouth. All estuaries except the Narmada have wide mudflats. This is because all estuaries have meanders, which allow dampening of more land by tidal water as compared to the straight bank estuaries like the Narmada estuary. This has given rise to wide mudflats along all the major estuaries. The sedimentation in the Tapi and the Kalubhar estuaries is a serious problem as it affects navigations and port operations.

**Mudflats**

Extensive mudflats, 6-8 km wide have developed all along the coast of the Gulf of Cambay except along the Narmada estuary. These mudflats are classed on
the basis of their relation with tidal condition into subtidal, intertidal and the high
tide flats (Davies, 1972). The subtidal zone is exposed during very low tide. The
intertidal slope lie between high water and mean low water mark. Subtidal zone
includes submerged shoals and mudflats. Submerged shoals are occurring in the
Dhadhar, the Narmada, the Kim estuaries and on the Saurashtra coast. The shoals
on the Saurashtra coast were not visible during the year 1975 (Nayak & Sahai,
1984, 1985). It indicates recent heavy deposition in the Gulf. The mudflats of this
zone are barren and are present in the Dhadhar, the Kim and in the Kalubhar
estuary. Intertidal slope includes three types of mudflats. Type I mudflats run
along the coast between the Sabarmati and the Tapi estuaries, type II are found
between the Narmada and the Tapi and Type III are found on the Saurashtra
coast. The difference in these mudflats is mainly because of different nature of the
source material. The Type I mudflat sometimes have either marsh or grass on it as
seen between the Mahi and the Dhadhar estuaries. Mangroves are found mainly
on the Aliabet Island in the Narmada estuary. Grass is found around the Kim
estuary and on Aliabet Island in the Tapi estuary. At many places, between
Narmada and Tapi estuaries, patches of alluvium are found within mudflats.

High tide flats are divided into six different types of mudflats. Type I
mudflat is mainly found between the Mahi and the Tapi estuaries. It covers the
largest area. These mudflats are sometimes covered with either salt as in South of
Dhadhar, or vegetation as in South of the Kim river and on the Aliabet Island in
the Narmada estuary. Part of mudflat is reclaimed and crops are grown in the
South of Tapi estuary. Type II mudflats are found around the Mahi estuary only.
These mudflats near Dabka are reclaimed and being used to grow crops.
Sometimes they sustain thick babul growth also and are classified as mudflat II
with vegetation (Nayak & Sahai, 1985).

Type III mudflats are found along the creeks of the Saurashtra side. Their
composition is distinctly different and their origin is mainly marine in nature.
Type IV mudflats are found within Type V mudflats, along the Saurashtra Coast
(north of the Kalubhar estuary). They are slightly on higher ground and escape
submergence during normal high tide. They are slightly on higher ground and
submergence during normal high tide. They are often covered by babul. Type V
mudflats cover a large area on Saurashtra coast. Type VI mudflats are found
around the Shetrunji estuary. They are covered by thin veneer of salt (Nayak &
Sahai, 1985).

The above-mentioned mudflats are differentiated on the basis of the
difference in tone and texture which may be due to variation in the constitution or
size of sediments. The fine-grained silt and clay form the mudflats. The source
material is mainly fluvial in nature, that is, sediments brought down by rivers.
Other sources are sediments derived from cliff erosion and insitu reworking of
sediments within estuary. These sediments are deposited by flocculation process.
Tidal currents play an important role in formation of these mudflats. Most of
sediments have been deposited during slack period (Nayak & Sahai, 1980).

These mudflat exhibit marked break in slope at the high tide mark and
inbetween high and low tide mark. Possibly because of these reasons, two distinct
boundaries are visible on the satellite imagery. These mudflats can also be classed
as vegetated or non-vegetated on the basis of presence or absence of vegetation
on them.

The mudflats, north of Gulf as well as between the Mahi and the Narmada
estuaries, lying above the high tide flats are termed as paleomudflats (Nayak and
Sahai, 1984, 1985). These mudflats are related to phenomena of regression of sea.
These mudflats are utilized for growing crops and shows transition from these
flats to good agricultural land.

**Islands**

There are many islands in the Gulf. The islands at the mouth of estuaries
are designated as mouth bars (Nayak & Sahai, 1984, 1985). The Narmada, the
Tapi, the Mahi and the Sabarmati have mouthbars. They have smooth outline and
normally above the high water line, and are composed of either sand or silt and
clay and free from rocks. The Islands at the mouth of the Narmada and the Tapi
are wide in their areal extent. These islands in the Mahi and the Sabarmati are mainly sand in nature. This probably indicates predominance of fluvial deposition in the Tapi river. The Piram Island is composed of hard conglomerates with clifffy shore. It is 5km across and aligned in NW-SE direction.

Apart from these islands, there are many shoals present in the Gulf, especially at the mouth of estuaries. Shoals are generally composed of sand and remain submerged under water. Many new shoals are seen especially near the Saurashtra coast and in the Narmada estuary west of Bharuch. This indicates high rate of sedimentation in the area.

**Mangroves/Marsh**

The mangroves refer to the community of plants, which colonise in soft muddy shores. The plants with their roots help in consolidating the loose muddy soil and build up a barrier between the tidal action from the sea and floods from the river. They are present in the Aliabet island in the Narmada estuary and near Gogha on the Saurashtra coast. They are mainly *Avicennia* species.

**Relict Alluvium**

Relict alluvium occurs within the mudflat II on intertidal slope. It is present between the Narmada and the Kim estuaries. The relict alluvium patches are few metres above the high water line. They reveal the sequence of transgression and regression of sea. They were the part of mainland when the shoreline was much lower than today. With the subsequent transgression the river valleys were drowned and the higher level patches were separated from the mainland which are engulfed in the present mudflat.

**Salt pans**

Salt pans are distributed all along the coast in the Gulf. Their number is more on the Saurashtra coast near Bhavnagar.
Transition Zones

Transitional zones are those lying between the paleomudflats and the plains between the paleomudflats and the plains between the Mahi and the Sabarmati rivers. They are closed into two zones based on vegetation density. These are usually reclaimed to grow crops.

Cliffs

Cliffs in this area are high, almost vertical. The entire course of the Mahi and the Narmada estuaries are marked by the presence of high alluvial cliffs. The cliffs present along the bank of Mahi have more altitude (10-20m) as composed to the Narmada where the height is 3-5m (Patel et al., 1985). The cliffs are an erosional feature.

Dunes

Dunes are present south of the Dhadhar river, near Dahej, and between the Tapi and the Narmada estuaries. They border the high tide mark and extend island upto 2-3 km. They run parallel to shoreline separated from each other by marked trough or valleys. They range in height from 2-3m usually heavily steep windward slope. Their crests are flat. They range in height from 2-3 in usually having steep windward slope. Their crests are flat. They are stabilized by the vegetation giving them different tone and texture other than the surrounding. These dunes may have formed due to exposure of vast expanse of sand which dries up at low tide on a low near-shore slope with strong on shore winds. Such a condition existed during the glacial period when the sea level was lower than today. Thus they represent former levels of sea and point to the regression of the sea. The dunes lying north of the Tapi estuary are surrounded by mud and are thus called cheniers.
**Flood plains**

Floodplain is a geomorphic feature representing the surface being constructed by the river. They usually run parallel to the river. They are subject to periodic overflow of river water. They are present along the river Tapi and the Sabarmati and are differentiated due to their elongated shape and the presence of the dense vegetation they support.

**Paleochannel**

A paleochannel is an abandoned course of the river. The Paleochannels identified along the Mahi and Narmada river, are actually edge of terraces as identified in of Mahi area. The oldest terrace is an impaired terrace and is formed due to slow and continuous rejuvenation with lateral erosion. These terraces can be attributed to the Flandrian transgression (early holocene) or the upliftment or both (Nayak et al., 1988). The terraces of the Mahi and the Narmada estuary are clearly recognized on the satellite imagery.

**Paleomeanders**

Paleomeanders are the old scars of the channel. They are present South of the Mahi estuary. They were initially delineated using IRS LISS- II data and later on TM data. The presence of paleomeanders indicates presence of older terrace

**Oxbow lake**

Oxbow lake is a cut-off portion of the meander of river. Oxbow lake is seen on the southern bank of the Mahi river, probably because of tectonic activity.

**Saline areas**

Saline area is present South of Surat. It houses the Udhana industrial complex.
3.5 Coastal Oceanography in relation to ecological dynamics

The Gulf of Cambay comprises the only segment of west coast where tides rise as high as 12 m. An interesting and important feature of the tidal phenomenon in the gulf is that apart from the rise and fall of water level, the tide generate very strong currents which both during the flood and ebb tides have been responsible for most of the depositional and erosional features in the onshore and offshore parts of the gulf. (Carlson, 1974) have prepared generalized maps of tidal current directions using Landsat data in the Gulf of Cambay during flood and ebb tide. The tidal current direction as observed during flood and ebb tides have almost identical paths and follow the bathymetric features of the gulf. Also the fanning pattern outside the mouth of the gulf is closely related to the presence of numerous underwater rhythmic linear ridges which regulates the entry exit of the tidal waters. Further, it is observed that the unevenness of the inner gulf bottom characterized by numerous mudbanks and shoals and the obstruction caused by Piram Island are also the factors that govern the movement of tidal waters. During the flood tide, the inflow of various mainland river waters experience a resistance, thereby slowing down or even reversing their flow direction. However, during the ebb tide, the river water joins the seawater in its outward journey. It thus stands out that the tidal currents are rather weak at the river mouths during flood tide, whereas they are quite strong during the ebb tide.

Currents

Current systems are very important in connection with various coastal processes and have a strong influence on the industrial, engineering, recreational and commercial activities conducted in this rapidly changing environment. The detection of direction and distribution of currents is of great help to coastal engineers in the prediction of sediment transport, outfall dispersion and their effect on coastal structures.

Current directions are indicated by the sediment-laden plumes as they become elongated in the direction of flow (Carlson, 1974). In the Gulf of
Cambay, the currents are mainly influenced by strong tides. Seasonal changes in current patterns are not pronounced, as can be seen from the Landsat imagery of September 1973 to March 1973 (Carlson *op.cit.*). During the flood tide, the currents move into the gulf. While after the flood tide and during the ebb period the currents move out of the gulf. Near the estuaries, the currents are mainly influenced by riverine discharge and shoreline configuration. The differences in depth of the bottom of the sea, where low-density water overlies denser water especially, if a sharp interface exists between them, induce slope currents (Pirie *et al.*, 1975).

**Waves**

Waves along the West Coast are generated by south westerly winds for the major part of the year.

**Bathymetry**

The bathymetry of the Gulf of Cambay is varied, and the bottom topography comprises a large number of shoals, underwater ridges and deep channels. The gulf bottom topography and cross-sections, based on Naval hydrographic maps reveal the unevenness of the gulf bottom which in turn points to the dominant role played by tectonics in imparting diversity to the gulf bathymetry. The features of the gulf bottom are essentially the product of graben faulting related to basin tectonism and deposition of sediment load by tidal currents.

**Erosion and Accretion**

For demarcating erosional as well as depositional changes, three images belonging to the same season (March 1973, 1975, and 1977) and more or less same tidal conditions were studied by Nayak & Sahai (1984). Pronounced changes were observed near the mouth of Sabarmati and Mahi, and on the
coastline south of Kambhat. Following observations were made by Nayak & Sahai (*op.cit*):

- The Sabarmati river has shifted its course after 1972.
- The shoreline South of Kambhat is being eroded away. Because of this, the cooling pond of Dhuvaran Thermal Power Station is threatened.
- Complex erosional and depositional changes are taking place in the mouth of the Mahi river. After 1972, the Mahi river has changed its course and shifted southwards to carve out two islands from the mudflats of the mainland. A shoal has started building up in the river channel, as seen in March 1975 imagery. In the March 1977 imagery, one more shoal is seen near the large island as compared to March 1975 imagery. This indicates deposition in the mouth. This is probably due to the effect of commissioning of Kadana dam. This dam now restrains the floods, which were flushing the sediments from the mouth and from shoals.
- When the shoreline on 1977 Landsat imagery is compared with the SOI topographical maps surveyed during 1868-1891, the following changes are noted which must have been brought about during the last hundred years.
- In the mouth of Sabarmati river, an island is seen now which is not marked in any SOI topographical map. The course of the Sabarmati river has also changed.
- Complex changes are noticed in the mouth of the Mahi river. An island shown on the topographical maps has now joined the mainland and numerous new shoals are seen at the mouth.
- The course of the Dhadhar river has changed slightly.
- Between the Sonarki Creek and Kalubhar river, a large island is shown on the topographical maps. This island has now joined the mainland.
- Erosional as well as depositional features are noticed in the mouth of Narmada river. Six islands are shown in the mouth of the Narmada river in the topographical maps. Instead of these only two islands including Aliabet are seen now. The size and shape of the Aliabet island has changed drastically.
The island has grown considerably. The river has narrowed down-stream of Bharuch on account of deposition of sediments in the mouth commissioning of Ukai dam.

- The course of the Mindhola river has also changed.

3.6 Landuse landcover characterization

Coastal Region

The coastal area around the Gulf of Cambay has acquired great importance in view of the development of fertilizer and allied chemical industries near Bharuch and Hajira, the thermal power station at Dhuvaran, the proposed landfall point of an oil pipeline near Ubharat, the proposed ferry service between Dahej and Gogha and the recently proposed tidal power station in the Gulf of Cambay. The geomorphic processes of erosion, sediment transport, deposition, and the extent and condition of tidal wetlands greatly influence these industrial and commercial activities.

The coastline of the gulf is made up of geologically diverse rocks and its geomorphic features typically reveal various combinations of geological factors like lithology, structure and sea-level changes due to neotectonism and glacio-eustasy. These factors have not only controlled the gulf configuration and bathymetry, but are responsible for the generation, and controlling the behaviour of offshore processes like tides, tidal currents and wave actions (Badrul, 1986).

The present day gulf coastline mainly consists of Quaternary sediments, but the existing coastline configuration and coastal geology however have been controlled by the tectonic and depositional processes, marine as well as fluvial, that were initiated much earlier, almost at the beginning of Cenozoic. The Tertiary geology has provided the basic framework, which has been acted upon and influenced by the subsequent fluvial and coastal marine processes.

Geomorphologically, the different parts of the Gulf are quite distinct. Whereas the coastal areas on the Saurashtra side consist of landforms related to
the Tertiary and Quaternary periods, those on the Mainland are exclusively Quaternary. The various erosional and depositional landforms that are observed along the Saurashtra coast are wave cut platforms, cliffs and stacks, backshore miliolothic dune complex, backshore paleodunes, recent coastal dunes, mudflats, alluvial plains and alluvial islands (bets). On the other hand the Mainland coast is made up of a thick accumulation of Quaternary fluviatile sediments and provides a good example of a drowned alluvial coast. The coast is endowed with estuarine river mouths, foreshore mudflats and offshore mudbanks, older mudflats, relict alluvial patches within mudflats, beaches and sandy ridges.

**Soil classification**

Soil is the most valuable life supporting natural resource. The soil forming processes are influenced by geology, physiography, climate and vegetation. The land around the Gulf of Khambhat (Cambay) has been formed under fluviomarine environments and therefore the soils of the area have inherent salts in their composition. The changing environmental conditions and human interventions have caused increase in the spread and concentration of soil salinity over the past several decades. It is seen that in the course of the last three decades, the environment has fast degraded and the problem of soil salinity has got aggravated. An attempt is made here to highlight the extent of salinity spread in the area around the gulf. The salt concentration increases with depth. Its lateral distribution generally follows the topography. Greater concentration is found along the low lying coastal zone and the linear depression joining Khambhat and Kharaghoda. Present day marine influence in the form of tides, creeks, cyclonic storms and seawater ingress also increase salt concentration in coastal land. Faulty agricultural practices including brackish groundwater lift and intensive canal irrigation also add salts to the farm lands. High rate evaporation of the arid environment also enhances the process of bringing out salt from lower sediments to the surface. Evidently, several pockets of dry salt waste and Rann are
progressively increasing especially in Bhal region of the study area. All these lead to degradation of land and water resources resulting into ecological disruption.

Salt encrustation and saline soils

The soils in this saline coastal belt are non-homogeneous. This is reflected in the diversified ecological and environmental impacts on the region. The soils in the areas, south and southwest of Sabarmati have deep black clay soils whereas in the western and north-western region they are 'medium' (from clay loam to sandy clay loam) in texture. The soils in the sea estuaries near range from sandy clay loams to silty clays in texture. The moisture holding capacity ranges from 28 to 57 percent and the permeability of the least permeable layer (on disturbed soil samples) ranges from 0 to 1-cm/ sec to impervious. The soil salinity on 1:2 soil:water ratio at different depths from surface to 180 cm indicate high to very high salt concentrations varying from less than 1 dS/m (Desi Simmens per Meter) to more than 15 dS/m. Salinity in the mud flats is still more i.e. upto about EC 40 dS/m. The pH values of the soils ranges from 7.1 to as high as 9.6. The areas indicating exchangeable sodium percentage of more than 15% (Alkali soils) occur in small patches. More than 42% of the area have soils heavily impregnated with soil salinity of more than 3 dS/m to as high as more than 15 dS/m and are presently unsuitable for irrigation. They need adequate reclamation and drainage measures for bringing them under cultivation.

Vegetative landcover

The vegetative landcover comprising of agriculture, shrubs, reserve forests, grasslands and mangroves are given as under:

a. Agriculture

Major crops of the area are cereals ,viz., rice, wheat, jowar, bajra and kodra. Maize is also emerging as a major crop in the last decade. These cereals constitute about 50% of the net sown area while their proportion for the State is around 30%. In the study area, cash crops e.g. oil seeds and cotton form a very
small proportion (10%) of the net sown area while their proportion for the State is around 40%. The area represents a heterogeneous agroecological pattern, which is a reflection of a diversity of physiographic setup, soil types, climatic conditions and length of growing period. The external inputs like irrigation, fertilizers, pesticides, including crop selection under market forces are the other important factors determining the cropping pattern. The region between Narmada and Mahi (Bara tract) comprising four talukas has generally a rainfed cropping with limited groundwater lift irrigation. The area used to give good cotton crop on groundwater lift till late eighties, but as the groundwater turned saline, cotton disappeared leaving behind degraded soils. The region between Mahi and Sabarmati covering four talukas of Kheda district has perennial canal irrigation and land suffers from waterlogging, salinity hazard and monocropping practices.

b. Shrubs

The natural vegetation in degraded salt affected soils is very poor and is formed of stunted and scattered species of Prosopis juliflora, Acacia nilotica, Capparis decidua, Prosopis cineraria, Salvadoria persica, Salvadoria oleoides, Zizyphus nummularia, Tamarix ericoides, Kochia prostrata, Cassia auriculata, Cressa cretica, Cynodon dactylon etc. Rao et al. (1993) have made an exhaustive compilation of the typical shrubs of the area around the gulf.

c. Reserve forests

Two biodiversity areas of the State viz. The Velavadar National Park and the Nal Sarovar Bird Sanctuary are located in the study area. These are classified as rich areas on the basis of forest/wetland where total floral and faunal components are abundant and frequented by migratory birds.

(i) Velavadar National Park

The Velavadar National Park is situated in the Bhal region, to the north of Bhavnagar near Vallabhipur off the Ahmedabad-Bhavnagar State highway. It
represents forest area with abundant floral and faunal components. The Park has a rich unique grassland ecosystem reminding one of the vast African plains. This sanctuary is known for the single largest population of blackbuck in the country. It also harbours wolf, nilgai, jackal and fox. Lesser florican breeds here and the grasslands are the home to other various smaller creatures. A great variety of birds, many of which are migrants made this sanctuary attractive to bird watchers. It is protected under several legal and administrative provisions since last 20 years. It also gives indication of past natural vegetation and dependent animal life. The list of plants and animals including birds found in Velavadar and surrounding Bhal regions is recorded in draft management plan and working plan of the State Forest Department (GEC, 1997).

(ii) Nal Sarovar Sanctuary

The Nal Sarovar Bird Sanctuary represents the wetland biodiversity, which is frequented by abundance of migratory birds. The sanctuary represents a unique wetland ecosystem supporting a high level of biodiversity on which the socio-economic lives of the people of surrounding area also depends. Moreover, it is the wintering ground for migratory birds and therefore occupies a place in the ornithological map of the world. The Nal Sarovar is a natural lake representing a dead sea. Its catchment of about 2300 sq. km and the water spread of 115 sq. km at 10.0 m filling level AMSL (Above Mean Sea Level). Water depth varies from 0.5 m to 2.0 m with storage capacity of 66 MCM (Million Cubic Meter). There are about 360 islands most of which get exposed when water level drops. Although, the lake area itself is without any vegetation cover, it provides good habitation for aquatic flora and fauna. The low-level land covering about 325 sq. km falls under influence of monsoon inundation at 12m flood level. The wet area shrinks considerably in summer and water turns saline. Thus the area has a strong seasonal character. The vast wetland is a totally different habitat from the surrounding country and harbors more than 250 species of birds, many of which are migratory flock and come between December and February from Europe, Asia
and Siberia. The 115 sq. km area of this wetland was declared a Bird Sanctuary in the year 1969. In 1982, some 5.82 sq. km area was added, and at present it is 120.82 sq. km. Of late attempts have been made to upgrade its protection and management. Due to its vastness and unique location on the migration routes of the birds, it is recognized as one of the important waterfowl habitation in Western India. In general, the vegetation on the Nal Sarovar shore is sparse and scattered. However, plant species like *Salvadora persica, Prosopis juliflora* are dominant and *Zizyphus jujuba, Acacia nilotica* and *Capparis aphylla* are common. The aquatic flora consist of algae, bryophytes and angiosperms including genus *Typha, Cyperus, Nymphaea, Zontera, Zizinia, Valliseria, Ceratophyllum, Petamogeton* and *Hydrilla*. In shallow water, reeds and sedges are very common. As the water recedes, grasses become abundant. The animal life consists of many forms of aquatic invertebrates including nematodes, snails, bivalves, crustacea and insects. Vertebrates are represented by fish and frogs. Birds such as cormorants, pelicans, whistling teals, comb ducks, pochards, coots, gulls, terns, dabbling ducks, ibises and spoonbills are also found.

Apart from these two hot spots abundant in floral and faunal diversity, Gulf of Cambay is also characterized by fish species diversity at different depths, which is shown in Figure 3.5 (Adapted from GEC, 1997).

d. Grasslands

The major part of the area, being covered by salt affected soils occurring under diverse agroecological conditions, usually found barren and occasionally support sparse native vegetation comprising woody plants and/or hardy grass as surface cover. The vegetation cartography of the area has been covered under the regional survey by the French Institute of Pondicherry (FIP). The FIP compiled the vegetation data prior to 1960 from various sources and adequately supported by field checks. A vegetation status map of the area based on FIP survey shows the coastal and inland saline areas with natural vegetation of salt marsh and
mangrove. The major types in the surrounding dry areas are mainly discontinuous thorny thickets, scattered shrub and shrub savanna (Patel et al., 1992).

e. Mangroves

The importance of mangroves has already been discussed earlier in this chapter including the changes undergone by them. The mangroves of the Gulf of Khambhat are mainly *Avicennia* species. However it may be noted that the Gulf of Cambay region is not rich in mangrove vegetation and accounts only for five percent of the total mangroves of Gujarat. Along the entire coastline of the Gulf, Bhavnagar, Bharuch and Surat are the areas where the major mangrove patches are found.

**Water Resources**

a. Drainage

The western part of Gulf of Cambay, especially the region north to Gogha presents an intricate network of creeks. These creeks make passage of fishing vessels and smaller crafts possible but in the ebb they drain enormous amounts of sediments into the gulf. These creeks play a vital role in the long-term geomorphological changes of the coast. A large-scale afforestation of this basin with mangrove plants like *Rhizophora* sp. and *Avicennia* sp. could arrest the sediment movement to some extent.

b. Ponds and Lakes

The area is characterised by presence of a large number of inland water bodies in the form of ponds, tanks and lakes. The locations of the water bodies are generally the sites of the old river meanders and shifting stream courses. Such natural features were developed and maintained by the people in the past. They used to serve the fresh water needs of the people for water supply and Kharif irrigation. The wells located in the bed and on the banks of the ponds were the
sources of drinking water in the otherwise saline groundwater all around. The local people used to regularly maintain them. The ponds had a very important role in the economic activities and socio-cultural traditions of the people. During the days of the old princely rule, the pond received maximum attention and care, as is evident from the structural designs and architectural importance attached to them. During last few decades, the ponds have lost public attention with the introduction of the schemes of exogenous fresh water supply for drinking and irrigation. Due to such neglect, the ponds gradually got silted up reducing the size, storage capacity and recharge potential. Many a time, the land of the silted pond has been used as agricultural land. The fresh water storage in the ponds and river used to suppress the salinity of land and groundwater. The reduction of fresh water pools in the area has significantly contributed towards increasing the salinity.

c. Canals

The development in irrigated agriculture, during the last few decades has reflected in progressive increase of groundwater extraction. However, in areas of canal irrigation the case is reverse. In areas where there is no canal facility and the groundwater is saline at depth, irrigation has not developed. In the study area, such cases have been observed. It is seen that in the Kheda area where there is perennial canal irrigation, there is hardly any groundwater lift. In such areas groundwater levels in open wells have risen in the range of 1-10m, average rise being 5m. The rising water table has created problems of waterlogging and salinity increase. In rest of the areas where there is no canal facility, and irrigation is done by groundwater lift, the water levels in wells have depleted in the range of 1 m to 10 m; the average depletion being around 4 m. Progressive quality deterioration with depth have restricted further extraction and depletion of level (GEC, 1997).